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कार्मिक और पर्यावणीय मानीटरों के लिए तापसंदीप्ति मात्रामिति

Indian Standard

THERMOLUMINESCENCE DOSIMETRY SYSTEMS FOR PERSONAL AND ENVIRONMENTAL MONITORING

UDC 539·12·08 : 535·377

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NEW DELHI 110002

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NATIONAL FOREWORD

This Indian Standard which is identical with IEC 1066 : 1991, 'Thermoluminescence dosimetry systems for personal and environmental monitoring', issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of tho Nuclear Instrumentation Sectional Committee (LTD 26) and approval of the Electronics and Telecommunication Division Council.

In the adopted standard certain terminology and conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.
b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

Only the English language text in the international standard has been retained while adopting it in this Indian Standard.

Indian Standard

THERMOLUMINESCENCE DOSIMETRY SYSTEMS FOR PERSONAL AND ENVIRONMENTAL MONITORING

1 Introduction

Thermoluminescence dosimetry (TLD) systems consist essentially of the following elements:

a) a passive device, referred to here as a dosemeter, incorporating some means of identification and containing one or more detectors exhibiting the property of thermoluminescence (TL);

b) a reader which is used for heating the detector or detectors after exposure to ionizing radiation and for measuring how much light is emitted on heating, in order to determine the radiation dose;

c) other additional equipment and documented procedures for performing associated processes, such as annealing or cleaning, which may be needed to ensure the effectiveness of the whole system;

d) documented procedures for converting the measured light output into dose and for handling the resulting data.

Provision is made for testing the performance of either an entire thermoluminescence dosimetry (TLD) system, dosemeters, detectors or readers tested separately. While items c) and d) are not addressed specifically, they are indirectly tested as part of the TLD system.

The performance criteria for the entire TL system are the most comprehensive and have been so designed that compliance ensures adequate performance of the system tested for use in personal and environmental dosimetry consistent with the state of the art.

The performance criteria for detectors tested separately include only those criteria that are clearly dependent primarily on the detector and essentially not influenced by other components needed for testing. Hence, the criteria are restricted only to those that are meaningful for a detector regardless of the remaining components used to complete a system. This principle likewise applies to readers tested separately.

Some of the performance requirements specified in this standard for thermoluminescence dosimetry (TLD) systems may also be used for the design of TL dosemeters for which purpose the performance requirements for TLD systems identified in table 1, items 1 to 11 inclusive, are appropriate.

Only some specific tests may be carried out on the reader and the results are independent of the dosemeters used. These points are emphasized in order to reduce the number of tests needed to qualify the system (see 8.4).

The annexes provided in this standard are considered useful for the understanding of the dosemeters and shall be taken as informative.

Compliance with the performance criteria for dosemeters, detectors or readers tested separately does not guarantee that any system including these components will comply with the performance criteria for thermoluminescence dosimetry (TLD) systems.

2 Scope and object

This standard provides performance criteria and tests for determining the performance of thermoluminescence dosimetry (TLD) systems, dosemeters, detectors or readers used for *personal dosimetry* involving photons with energies between 15 keV and 3 MeV and beta rays with maximum energies between 0,5 MeV and 3,0 MeV. It does not address neutrons or mixed fields including neutrons. Where the response to neutrons is greater than 1 % of the response to photons, the manufacturer shall draw the attention of the user to this fact and where possible provide qualitative information. The quantity used in this standard for personal dosimetry is individual dose equivalent at depths of 7 or 1 000 mg $\cdot$ cm^{-2}. Conversion tables are provided for calculating the directional dose equivalent from kerma in air (annex A).

This standard also provides performance criteria and tests for thermoluminescence dosimetry (TLD) systems, dosemeters, detectors or readers used for *environmental dosimetry* involving photons with energies between 30 keV and 3 MeV. It does not specifically address beta or cosmic rays. The quantity used in this standard for environmental dosimetry is ambient dose equivalent. Conversion tables are provided for calculating the ambient dose equivalent from kerma in air (annex B).

In all cases, performance is assessed under laboratory conditions which can never adequately simulate the conditions actually experienced in personal or environmental dosimetry. Therefore, caution is necessary when applying the results of these performance tests in real situations.

This standard does not incorporate requirements for extremity dosemeters or neutron dosemeters nor does it cover access to the information or handling of the resulting data.

3 Reference documents

ISO 4037: 1979, *X and gamma reference radiations for calibrating dosemeters and dose ratemeters and for determining their response as a function of photon energy.*

ISO 6980: 1984, *Reference beta radiations for calibrating dosemeters and doseratemeters and for determining their response as a function of beta radiation energy.*

ICRU Report 33: 1980, *International Commission on Radiation Units and Measurements - Radiation quantities and units.*

ICRU Report 39: 1985, *International Commission on Radiation Units and Measurements - Determination of dose equivalents resulting from external radiation sources.*

4 Definitions

4.1 **thermoluminescence (TL):** Property exhibited by certain substances, namely the emission of light, which is induced by irradiation when the substance is heated following exposure to ionizing radiation or UV. Strictly, the property should be referred to as radio-thermoluminescence but the abbreviated form thermoluminescence is usually adequate.

4.2 **thermoluminescent (TL) material:** Substance exhibiting the property of thermoluminescence.

4.3 **thermoluminescent (TL) detector (abbreviation - detector):** Specified quantity of TL material, or such material incorporated with other non-luminescent material into a matrix, being defined by mass, shape or size or the mass of material incorporated in the matrix.

4.4 **thermoluminescent (TL) dosemeter (abbreviation - dosemeter):** Passive device consisting of one or more TL detectors, which may be mounted in a holder (appropriate for the application), intended to be worn on a person's body or placed in an environment for the purpose of assessing the appropriate dose equivalent at or near the position where it is placed.

4.5 **thermoluminescent (TL) dosemeter reader (abbreviation - reader):** Instrument used to measure the light emitted from the detectors in thermoluminescence dosemeters, consisting essentially of a heating device, a light measuring device and the associated electronics.

4.6 **thermoluminescence dosimetry (TLD) system (abbreviation - system):** The TL dosemeter, reader and all associated equipment and procedures used for assessing the evaluated value.

4.7 **environment:** Areas to which members of the general public have unrestricted access.

4.8 **environmental dosemeter:** Dosemeter intended to be placed in the environment.

4.9 **personal dosemeter:** Dosemeter intended to be worn on the body.

4.10 **type of system, detector or reader:** Dosemeters, detectors or readers made to the same design and specification and expected to have the same properties as each other within specified limits.

4.11 **batch (of detectors or dosemeters):** Collection of detectors or dosemeters made to a specific design or specification and intended to have the same performance characteristics consistent with the appropriate requirements of this standard.

4.12 **annealing:** Controlled thermal treatment of a TL detector or dosemeter during or after readout.

4.13 **prepare:** Normal treatment of annealing, cleaning, etc., which the dosemeters or detectors are intended to be subjected to in routine use.

4.14 **readout:** Process of measuring the light emitted when a thermoluminescence detector is heated in a reader.

4.15 **readout value** *r*: Value indicated by a TL reader after readout of a detector expressed in units appropriate to the output of the reader.

4.16 **exposure** *X*: Quotient of d*Q* by d*m* where the value of d*Q* is the absolute value of the total charge of the ions of one sign produced in air when all the electrons (negatrons and positrons) liberated by photons in air of mass d*m* are completely stopped in air:

$$X = \frac{\mathrm{d}Q}{\mathrm{d}m}$$

NOTE - The special unit of exposure, roentgen R, may be used temporarily:

$$1\ \mathrm{R} = 2{,}58 \times 10^{-4}\ \mathrm{C \cdot kg^{-1}}\ \text{(exactly)}$$

4.17 **absorbed dose** *D*: Quotient of $\mathrm{d}\bar{\varepsilon}$ by d*m*, where $\mathrm{d}\bar{\varepsilon}$ is the mean energy imparted by ionizing radiation to matter of mass d*m*. The special name for the unit of absorbed dose is gray Gy:

$$1\ \mathrm{Gy} = 1\ \mathrm{J \cdot kg^{-1}}$$

The special unit of absorbed dose, rad, may be used temporarily.

$$1\ \mathrm{rad} = 10^{-2}\ \mathrm{Gy}$$

In this standard, absorbed doses are specified in grays, with the corresponding value in rad given in brackets. Where no ambiguity can be involved, the term "absorbed dose" is abbreviated to "dose".

4.18 **kerma** *K*: Quotient of $\mathrm{d}E_{tr}$ by d*m*, where $\mathrm{d}E_{tr}$ is the sum of the initial kinetic energies of all the charged ionizing particles liberated by uncharged ionizing particles in a matter of mass d*m*:

$$K = \frac{\mathrm{d}E_{tr}}{\mathrm{d}m}$$

The special name for the unit of kerma is gray Gy:

$$1\ \mathrm{Gy} = 1\ \mathrm{J \cdot kg^{-1}}$$

4.19 **dose equivalent** *H*: Product of *D*, *Q* and *N* at the point of interest in tissue where *D* is the absorbed dose, *Q* is the quality factor and *N* is the product of all other modifying factors:

$$H = DQN$$

The SI unit for both D and H is joule per kilogram. The special name for the unit of dose equivalent is sievert Sv:

$$1\ \text{Sv} = 1\ \text{J} \cdot \text{kg}^{-1}$$

The special unit of dose equivalent, rem, may be used temporarily:

$$1\ \text{rem} = 10^{-2}\ \text{Sv}$$

4.20 **ambient dose equivalent $H^*(d)$**: Ambient dose equivalent, $H^*(d)$ at a point in a radiation field, is the dose equivalent that would be produced by the corresponding aligned and expanded field (note 2) in the ICRU sphere at a depth, d, on the radius opposing the direction of the aligned field.

NOTES

1 The recommended depth, d, for monitoring in terms of $H^*(d)$ is 10 mm and $H^*(d)$ may be written as $H^*(10)$.

2 In the *expanded field*, the fluence and its angular and energy distribution have the same values throughout the volume of interest as in the actual field at the point of reference. In the *aligned and expanded field*, the fluence and its energy distribution are the same as in the expanded field but the fluence is unidirectional.

4.21 **directional dose equivalent $H'(d)$**: Directional dose equivalent, $H'(d)$ at a point in a radiation field, is the dose equivalent that would be produced by the corresponding expanded field (see 4.20, note 2) in the ICRU sphere at a depth, d, on a radius in a specified direction.

NOTE - The recommended depth, d, for monitoring in terms of $H'(d)$ is 0,07 mm and $H'(d)$ may be written as $H'(0{,}07)$.

4.22 **individual dose equivalent, penetrating $H_p(d)$**: Individual dose equivalent, penetrating, $H_p(d)$, is the dose equivalent in soft tissue below a specified point on the body at a depth, d, that is appropriate for strongly penetrating radiation.

NOTE - The recommended depth, d, for monitoring in terms of $H_p(d)$ is 10 mm, and $H_p(d)$ may be written as $H_p(10)$.

4.23 **individual dose equivalent, superficial $H_s(d)$**: Individual dose equivalent, superficial, $H_s(d)$, is the dose equivalent in soft tissue below a specified point on the body at a depth, d, that is appropriate for weakly penetrating radiation.

NOTE - The recommended depth, d, for monitoring in terms of $H_s(d)$ is 0,07 mm and $H_s(d)$ may be written as $H_s(0{,}07)$.

4.24 **evaluated value E**: Value of the quantity of interest (e.g. directional dose equivalent $H'(10)$; air kerma K_a obtained by applying the appropriate evaluation factor, F_e, to the readout value or values r).

4.25 **conventional true value C**: Best estimate of the quantity of interest at the point of measurement (e.g. directional dose equivalent $H'(10)$; air kerma K_a).

4.26 **evaluation factor F_e**: Factor, or collection of factors, used to convert the readout value or values r to the evaluated value of interest E (see annex C).

4.27 **residue signal:** Readout signal obtained on second readout following normal readout and annealing procedures.

4.28 **conversion factor** F_c: Factor used to convert from air kerma to the corresponding dose equivalent (see annexes A and B).

4.29 **response** R: Quotient of the evaluated value and the conventional true value.

4.30 **self-irradiation:** Irradiation of the detector due to radioactive impurities contained in the dosemeter holder or detector itself.

4.31 **phantom:** Specified object used to simulate the human body in terms of its scattering and absorption of gamma and beta radiation.

4.32 **zero point:** Evaluated value of an unirradiated prepared dosemeter.

4.33 **reader background:** Evaluated value corresponding to the readout value obtained when the reader is operated without a dosemeter or detector.

4.34 **detection threshold:** Minimum evaluated value for which the readout value of a dosemeter is significantly different (at the 95 % confidence level) from the readout value of an unirradiated dosemeter.

4.35 **coefficient of variation:** Ratio V of the standard deviation, s, to the arithmetic mean $\overline{x}$ of a set of n measurements x_i, given by the following formula:

$$V = \frac{s}{\overline{x}} = \frac{1}{\overline{x}} \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \overline{x})^2}$$

4.36 **routine test RT:** Test performed on each TLD system, dosemeter, detector or reader to determine performance characteristics.

4.37 **quality control test QT:** Test performed on a number of TLD systems, dosemeters, detectors or readers of a given batch or production designed to ensure quality control.

4.38 **type test TT:** Test performed on a small number of TLD systems, dosemeters, detectors or readers of a given type to determine performance characteristics of that type.

5 Units

This standard uses SI units. For radiation quantities, the values expressed in units in temporary use (R, rad, rem) are also indicated in brackets. The following units of practical importance will also be used where appropriate:

- for time: years (y), days (d), hours (h), minutes (min), and
- for energy: electronvolt (eV).

6 General test conditions

6.1 *Testing conditions*

All tests shall be performed under standard test conditions (table 4), except when otherwise stated. Systems, detectors and readers shall be tested in the manner in which they are expected to be used during routine personal or environmental dosimetry. For example, detectors shall be subjected to the annealing, cleaning and handling procedures recommended by the manufacturer.

6.2 *Reference radiations*

All tests involving the use of irradiated dosemeters or detectors shall be carried out using the radiation sources as specified in ISO Standard 4037 and ISO Standard 6980.

Photon reference radiations used for spectral response tests shall be chosen from column A of the table 1 in 3.1 of ISO Standard 4037. Sources for beta radiation spectra response tests shall be ^{90}Sr (in equilibrium with ^{90}Y) and ^{204}Tl in accordance with ISO Standard 6980.

The calibration of the radiation sources used shall be traceable to the appropriate primary or secondary standards.

7 Classification and designation

7.1 *Classification of systems, detectors and readers*

All systems, detectors and readers are classified according to use: personal (P_e) and/or environmental (E_n).

Systems, detectors and readers intended for use in personal dosimetry are further classified according to the dose equivalent of interest in terms of depth in tissue, either 7 or 1 000 $mg \cdot cm^{-2}$.

Systems, detectors and readers intended for use in environmental dosimetry are further classified according to the lower energy of X or gamma radiation that they are intended to measure, either 30 keV or 80 keV, and then according to the minimum period of use for which they are suited, either seven days (7 d) or thirty days (30 d).

7.2 *Designation of systems, detectors and readers*

For personal dosimetry, systems, detectors and readers are designated by the following notation:

P_e (dose equivalent of interest expressed as depth in tissue in $mg \cdot cm^{-2}$).

For environmental dosimetry, systems, detectors or readers are designated by the following notation:

E_n (lower energy in keV) (minimum use period in days).

Example	*Designation*
TLD system intended to measure dose equivalent at 7 mg . cm^{-2}	P_e (7 mg . cm^{-2})
TLD system intended to be used for all personal and environmental dosimetry	P_e (all); E_n (all)
TL detector intended to be used for environmental dosimetry for energies as low as 30 keV and for periods as short as 1 week	E_n (30 keV) (7 d)
TL reader intended to be used for personal dosimetry	P_e (all)

8 Performance requirements and test methods

8.1 *General*

Performance criteria are summarized in table 1 for TLD systems, for readers in table 2 and for detectors in table 3. Only the performance criteria pertaining to a particular class of system, reader or detector need to be met for that class to comply with this standard.

If a detector and/or a reader are being tested as part of a system, they do not need to be tested for the performance criteria in tables 2 and 3, only for those in table 1. If readers or detectors are being tested separately, they need only be tested for the performance criteria in table 2 or table 3, respectively. Since, in most cases, detectors are incorporated in dosemeters for practical application, there are very few quantitative performance criteria for detectors alone that are relevant. However, information on basic detector performance is necessary. The ICRU sphere (ICRU Report 33, 1980) is a tissue-equivalent sphere, 30 cm in diameter, with a density of 1 g.cm^{-3} and a mass composition of 76,2 % oxygen, 11,1 % carbon, 10,1 % hydrogen and 2,6 % nitrogen. Therefore, compliance with this standard also requires that appropriate information be provided as indicated in table 3.

8.2 *Quantities of interest and calibration*

Performance criteria given in tables 1, 2 and 3 and the different tests are generally expressed in terms of the conventional true value *C* and of the evaluated value *E*. It is assumed that the uncertainty determining *C* can be neglected.

Table 1 - Performance requirements for TLD systems

No.	Performance characteristic	Class of system	Performance requirements	Test required TT = type QT = quality control RT = routine	Subclause specifying test
1	Batch homogeneity	All	The evaluated value for any one dosemeter in a batch shall not differ from the evaluated value for any other dosemeter in the batch by more than 30 % for a dose equal to 10 times the required detection threshold limit	RT	8.6.1
2	Reproducibility		The coefficient of variation of the evaluated value shall not exceed 7,5 % for each dosemeter separately and all *n* dosemeters collectively, for a dose of:	TT, QT, RT	8.6.2
		P_e (all)	10 mSv (1 rem)		
		E_n (all)(7 d)	50 µSv (5 mrem)		
		E_n (all) (30 d)	200 µSv (20 mrem)		
3	Linearity		The response shall not vary by more than 10 % over the range:	TT	8.6.3
		P_e (all) (7 mg · cm^{-2})	0,5 mSv - 1 Sv (50 mrem - 100 rem)		
		P_e (all) (1 000 mg · cm^{-2})	0,1 mSv - 1 Sv (10 mrem - 100 rem)		
		E_n (all) (7 d)	10 µSv - 100 mSv (1 mrem - 10 rem)		
		E_n (all) (30 d)	30 µSv - 100 mSv (3 mrem - 10 rem)		
4	Stability of dosemeters under various climatic conditions	All	The evaluated values of dosemeters irradiated either at the beginning or at the end of a storage period shall not differ from the conventional true value by more than:	TT, QT	8.6.4
			5 % for 30 d storage under standard test conditions		
			10 % for 90 d storage under standard test conditions		
			20 % for 30 d storage at 50 °C, 65 % relative humidity		
			20 % for 30 d storage at 20 °C, 90 % relative humidity		
5	Detection threshold		The detection threshold shall not exceed:	TT, QT, RT	8.6.5
		P_e (7 mg · cm^{-2})	0,5 mSv (50 mrem)		
		P_e (1 000 mg · cm^{-2})	0,1 mSv (10 mrem)		
		E_n (all) (7 d)	10 µSv (1 mrem)		
		E_n (all) (30 d)	30 µSv (3 mrem)		
6	Self-irradiation		After a storage period of 30 d, the zero point shall not exceed:	TT, QT	8.6.6
		P_e (7 mg · cm^{-2})	0,5 mSv (50 mrem)		
		P_e (1 000 mg · cm^{-2})	0,1 mSv (10 mrem)		
		E_n (all)	30 µSv (3 mrem)		
7	Residual signal	P_e (all)	After irradiation with a conventional true value of 100 mSv (10 rem), the required detection threshold shall not be exceeded and the response shall not change by more than 10 % at a dose level of 2 mSv (200 mrem)	TT	8.6.7
		E_n (all)	After irradiation with a conventional true value of 10 mSv (1 rem), the required detection threshold shall not be exceeded and the response shall not change by more than 10 % at a level of 0,2 mSv (20 mrem)		
8	Effect of light exposure on the dosemeter	All	As a result of exposure to 1 000 W · m^{-2} for 24 h, the zero point shall not change by more than the required detection threshold and for exposure for one week the evaluated value shall not differ from the evaluated value of dosemeters kept in the dark by more than 10 %	TT, QT	8.6.8

(continued on page 27)

Table 1 *(concluded)*

No.	Performance Characteristic	Class of system	Performance requirements	Test required TT = type QT = quality control RT = routine	Subclause specifying test
9	Energy response (photons)		When irradiated with photons in the range:	TT	8.6.9
		P_e (all) E_n (30 keV) (all)	15 keV - 3,0 MeV 30 keV - 3,0 MeV, the evaluated value shall not differ from the conventional true value by more than 30 %		
		E_n (80 keV) (all)	When irradiated with photons in the range 30 keV to 80 keV, the evaluated value shall not exceed the conventional true value by more than a factor of 2 and when irradiated with photons in the range 80 keV to 3 MeV, the evaluated value shall not differ from the conventional true value by more than 30 %		
10	Energy response (beta rays)	P_e (all)	When irradiated with beta rays in the range (E_{max}) 0,5 MeV to 3 0 MeV, the response shall not vary by more than 30 %	TT	8.6.10
11	Isotropy (photons)	P_e (all)	When irradiated in two perpendicular planes with photons of (60 ± 5) keV, the mean value of the responses at an angle of incidence of 20°, 40° and 60° from normal shall not differ from the corresponding response for normal incidence by more than 15 %	TT	8.6.11
		E_n (all)	When irradiated with ^{60}Co or ^{137}Cs while being rotated around three perpendicular axes using the centre of the dosemeter as the centre of rotation, the response shall not vary by more than 15 %	TT	8.6.11
12	Primary power supply voltage and frequency	All	The evaluated value of dosemeters read out under steady conditions of high and low voltage/frequency, shall not differ from the evaluated value of dosemeters read out under normal reader operating conditions by more than 5 %	TT	8.6.12
13	Transient voltage	All	The evaluated value of dosemeters read out following voltage transients shall not differ from the evaluated value of dosemeters read out under normal reader operating conditions by more than 5 %	TT	8.6.13
14	Effect of climatic conditions on reader	All	The reader background shall not vary by more than 20 % of the required detection threshold and the evaluated value shall not differ from the evaluated values determined under normal conditions by more than 10 % after and during exposure of the reader to the temperature and humidity conditions reported in the test	TT	8.6.14
15	Effect of vibration on reader	All	The evaluated value of dosemeters read out after exposure of the reader to sinusoidal vibration shall not differ from the evaluated value following read out under normal reader conditions by more than 5 %	TT	8.6.15
16	Dropping effect on dosemeter	All	The evaluated value of dosemeters read out after being dropped 1 m onto a concrete surface shall not differ from the evaluated value under normal conditions by more than 10 %	TT	8.6.16
17	Dropping effect on reader	All	The evaluated value of dosemeters read out after dropping the reader 1 cm onto a wood surface shall not differ from the evaluated value under normal reader conditions by more than 5 %	TT	8.6.17
18	Effect of reader light leakage	All	The reader background shall not vary by more than 20 % of the required detection threshold when the reader is exposed to 1 000 $W \cdot m^{-2}$ of light	RT	8.6.18

Table 2 - Performance requirements for TL readers

No.	Performance Characteristic	Class of system	Performance requirements	Test required TT = type QT = quality control RT = routine	Subclause specifying test
1	Reader stability	All	The evaluated values of dosemeters read out 24 h apart and 168 h apart shall not differ from each other by more than 5 % and 10 % respectively	RT	8.7.2
2	Primary power supply voltage and frequency	All	The evaluated values of dosemeters, read out under steady conditions of high and low voltage/frequency, shall not differ from the evaluated values of dosemeters read out under normal reader operating conditions by more than 5 %	TT	8.6.12
3	Transient voltage	All	The evaluated values of dosemeters, read out following voltage transient, shall not differ from the evaluated values of dosemeters read out under normal reader operating conditions by more than 5 %	TT	8.6.13
4	Effect of climatic conditions on reader	All	The reader background shall not vary by more than 20 % of the required detection threshold and the evaluated values shall not differ from the evaluated values determined under normal conditions by more than 10 % after and during exposure of the reader to the temperature and humidity conditions reported in the test	TT	8.6.14
5	Effect of vibration on reader	All	The evaluated values of dosemeters read out after exposure of the the reader to sinusoidal vibration shall not differ from the evaluated values following read out under normal reader conditions by more than 5 %	TT	8.6.15
6	Dropping effect on reader	All	The evaluated values of dosemeters read out after dropping the reader 1 cm onto a wood surface shall not differ from the evaluated values under normal reader conditions by more than 5 %	TT	8.6.17
7	Effect of reader light leakage	All	The reader background shall not vary by more than 20 % of the required detection threshold when the reader is exposed to 1 000 W · m^{-2} of light	RT	8.6.18

Table 3 - Performance requirements and information requested for TL detectors

No.	Performance Characteristic	Class of system	Performance requirements	Test required TT = type QT = quality control RT = routine	Subclause specifying test
			Performance requirements		
1	Batch homogeneity	All	The evaluated value for any one detector in a batch shall not differ from the evaluated value for any other in the batch by more than 30 % for a dose of 10 mGy (1 rad)	RT	8.8.2
2	Reproducibility		The coefficient of variation of the evaluated value shall not exceed 7,5 % for a dose of :	TT, QT	8.8.3
		P_e (all) E_n (all) (7 d) E_n (all) (30 d)	10 mGy (1 rad) 50 µGy (5 mrad) 200 µGy (20 mrad)		
			Information requested		
3	Linearity		The evaluated value (and standard deviation) relative to the conventional true value shall be given over the range:	TT, QT	8.9.1
		P_e (all) E_n (all)	0,1 mGy to 1 Gy (10 mrad to 100 rad) 0,03 mGy to 0,1 Gy (3 mrad to 10 rad)		
4	Energy response (photons)	All	The evaluated value (and standard deviation) relative to the conventional true value shall be given over the range 15 keV to 3 MeV	TT	8.9.3
5	Effects of light exposure on the detector	All	The zero point (and standard deviation) for detectors exposed to 1 000 W · m^{-2} for 1 d and the response after 1 week shall be given relative to those for detectors kept in the dark under conditions otherwise identical	TT	8.9.5

In the case of TLD systems, table 1, the units to be used for the relevant dose equivalent quantity are Sv (rem). In the case of readers (table 2) or detectors (table 3), kerma in air expressed in gray may be used for all classes.

Where applicable, readout values shall be converted to evaluated values according to the information and procedures given in annexes A, B and C.

All tests involving environmental TLD systems shall be performed with the dosemeter irradiated free in air. All tests for spectral response or isotropy involving personal TLD systems shall be performed with the dosemeter irradiated on a phantom (one possible phantom is the 30 cm-diameter ICRU sphere, see 8.1. Other phantoms are not excluded, provided that information be made available.)

Since the results of the remaining tests for personal dosimetry do not depend on the absence or presence of a phantom, they may be performed with or without a phantom.

8.3 *Type of test required*

Tests shall be performed as type tests (TT) (see 4.38), quality control tests (QT) (see 4.37), and/or routine tests (RT) (see 4.36) as indicated in tables 1, 2 and 3. Type tests shall be carried out to establish the basic performance of a type of system, detector or reader. Quality control tests shall be carried out to verify that the performance of a specific production or delivery batch of systems, detectors or readers is consistent with that type. Routine tests shall be performed on each system, detector or reader.

8.4 *Minimizing the numbers of tests*

Once a system has been type-tested, any other tests to be performed on dosemeters of that system type may be performed with any reader of that system type and vice versa.

In characteristics 1, 2, 3, 4 and 8 of table 1 where the performance requirements are the same for more than one class and the detectors used are the same for these classes, then the tests need to be done for only one class.

The tests for characteristics 12, 13, 14, 15, 16 and 17 need to be done with only one class or one type of dosemeters or detectors because the results are independent of all components in the system other than the reader. Consequently the results are valid for all systems incorporating the same reader.

8.5 *Number of dosemeters or detectors required for each test*

The number of dosemeters or detectors used for each test, or in certain cases the number of repeated tests shall be such that the performance requirements are demonstrated to be met with 95 % confidence. This number may be determined from the results of a series of repeated measurements on dosemeters within the batch being tested (e.g. during batch homogeneity measurements) using the methods described in annex D correcting, if necessary, for individual sensitivities. (For tests where the test dose is greater or equal to the test dose for the batch homogeneity test, the coefficient of variation of results from the batch homogeneity test may be used to determine *n*.) For tests where the coefficient of variation can be expected to be greater than that for batch homogeneity (e.g. tests with lower test doses or tests where the influence parameter may affect the coefficient of variation), it will be necessary to determine the coefficient of variation of results for that test and apply an appropriate Student's *t* factor.

The detailed test requirements therefore include appropriate statistical criteria in general terms for *n* dosemeters. However, it may be convenient to arbitrarily use 5, 10 or 20 dosemeters or irradiations in any given test by agreement between manufacturers and purchasers. In such a case, *n* would be 5, 10 or 20 and t_n would be 2,78, 2,26 or 2,09, respectively. (See annex D, table D.1).

8.6 *Requirements and test methods for TLD systems*

The different requirements and tests are expressed in terms of conventional true value *C* and evaluated value *E* where both quantities are intended to give the dose equivalent at the specified depth in tissue (as defined in ICRU Report 39) for personal dosimetry and the ambient dose equivalent (as defined in ICRU Report 39) for environmental dosimetry.

8.6.1 *Batch homogeneity*

8.6.1.1 *Requirements*

The evaluated value for any one dosemeter in a batch shall not differ from the evaluated value for any other dosemeter in the batch by more than 30 % for a dose equal to 10 times the required detection threshold limit.

8.6.1.2 *Test method* (RT)

Prepare and irradiate all dosemeters in the batch to the same conventional true value *C*, equal to 10 times the required detection threshold limit, e.g. a dose of 1 mSv (100 mrem) for P_e (1 000 mg · cm^{-2}). Determine the evaluated value *E* for each dosemeter and identify the dosemeters with the maximum and minimum evaluated values, E_{max} and E_{min} respectively.

Show that:

$$\frac{E_{max} - E_{min}}{E_{min}} \leq 0,3$$

8.6.2 *Reproducibility*

8.6.2.1 *Requirements*

The coefficient of variation of the evaluated value shall not exceed 7,5 % for each dosemeter separately and all *n* dosemeters collectively for a dose of:

- 10 mSv (1 rem) for class P_e (all);
- 50 µSv (5 mrem) for class E_n (all) (7 d);
- 200 µSv (20 mrem) for class E_n (all) (30 d).

8.6.2.2 *Test method* (TT, QT, RT)

Prepare, irradiate and read out each of *n* dosemeters. Repeat this 10 times. The conventional true value shall be exactly the same each time and about:

- 10 mSv (1 rem) for all class P_e dosemeters;
- 50 µSv (5 mrem) for class E_n dosemeters with a minimum use period of 7 days; and
- 200 µSv (20 mrem) for class E_n dosemeters with a minimum use period of 30 days.

For each dosemeter, determine E_{ji} where *j* refers to the *j*-th dosemeter and *i* refers to the *i*-th irradiation.

For each of the 10 irradiations, calculate the mean $\bar{E}_i$ and the standard deviation $s_{\bar{E}i}$.

Show that:

$$\frac{s_{\bar{E}i} + l_i}{\sum_{i=1}^{10} \bar{E}_i / 10} \leq 0{,}075$$

where l_i, confidence interval of $s_{\bar{E}i}$, is calculated according to D.2 of annex D.

For each of the *n* dosemeters, determine the mean value $\bar{E}_j$ and the standard deviation $s_{\bar{E}j}$.

where:

$$\bar{E}_j = \frac{1}{10} \sum_{i=1}^{10} E_{ij}$$

Show that for each of the *n* dosemeters:

$$\frac{s_{\bar{E}j} + l_j}{\bar{E}_j} \leq 0{,}075$$

where l_j is calculated according to D.2 of annex D.

8.6.3 *Linearity*

8.6.3.1 *Requirements*

The response shall not vary from the conventional true value by more than 10 % over the following ranges:

- class P_e (7 mg · cm^{-2}) systems - 0,5 mSv to 1 Sv (50 mrem to 100 rem);
- class P_e (1 000 mg · cm^{-2}) systems - 0,1 mSv to 1 Sv (10 mrem to 100 rem);
- class E_n (all) (7 d) - 10 µSv to 100 mSv (1 mrem - 10 rem);
- class E_n (all) (30 d) - 30 µSv to 100 mSv (3 mrem - 10 rem).

8.6.3.2 *Test* (TT)

Prepare, irradiate and read out four groups of dosemeters, where n_i is the number of dosemeters of the i-th group. The conventional true values C_i given to each group shall be as follows:

- class P_e (7 mg · cm^{-2}) - 0,0005; 0,001; 0,01; 0,1 and 1 Sv (0,05; 0,1; 1; 10 and 100 rem);
- class P_e (1 000 mg · cm^{-2}) - 0,0001; 0,001; 0,01; 0,1 and 1 Sv (0,01; 0,1; 1; 10 and 100 rem);
- class E_n (all) (7 d) - 0,01; 0,1; 1; 10 and 100 mSv (0,001; 0,01; 0,1; 1 and 10 rem);
- class E_n (all) (30 d) - 0,03; 0,1; 1; 10 and 100 mSv (0,003; 0,01; 0,1; 1 and 10 rem).

Calculate the mean evaluated value $\bar{E}_i$ at each irradiation level and its standard deviation $s_{\bar{E}i}$.

Show that:

$$0{,}90 \leq \frac{\bar{E}_i \pm I_i}{C_i} \leq 1{,}10$$

where I_i is obtained from D.3 of annex D for n_i dosemeters. The uncertainties over C_i are considered negligible.

8.6.4 *Stability of dosemeter under various climatic conditions*

8.6.4.1 *Requirements*

For all classes of systems, the evaluated values of dosemeters irradiated either at the beginning or at the end of a storage period shall not differ from the conventional true value by more than:

- 5 % for 30 days, storage under standard test conditions;
- 10 % for 90 days, storage under standard test conditions;
- 20 % for 30 days, storage at 50 °C, 65 % relative humidity;
- 20 % for 30 days, storage at 20 °C, 90 % relative humidity.

8.6.4.2 *Test method* (TT, QT)

A) Prepare two groups of n dosemeters each. Store both groups for 24 h under standard conditions.

Irradiate group 1 to a known conventional true value (C) of about: 10 mSv (1 rem).

Store both groups of dosemeters in a climatic chamber in which standard test conditions prevail.

After a continuous period of 30 days, remove both groups of dosemeters from the climatic chamber. Irradiate group 2 to the same conventional true value as group 1.

Store both groups for 24 h under standard test conditions.

Determine the evaluated value E for each dosemeter and calculate the mean of the evaluated values $\bar{E}$ for each of the two groups and the respective standard deviations $s_{\bar{E}}$.

Show that:

$$0{,}95 \leq \frac{\bar{E}\text{ (group 1, group 2)}}{C} \pm I \leq 1{,}05$$

where I is calculated according to D.3 of annex D.

B) Repeat the test specified in A) for a storage period of 90 days.

Show that:

$$0{,}90 \leq \frac{\bar{E}\text{ (group 1, group 2)}}{C} \pm I \leq 1{,}10$$

where I is calculated according to D.3 of annex D.

C) Repeat the test specified in A) for a storage period of 30 days but store in a climatic chamber in which the temperature is 50 °C ± 2 °C and the relative humidity is about 65 %.

Show that:

$$0{,}80 \leq \frac{\bar{E}\text{ (group 1, group 2)}}{C} \pm I \leq 1{,}20$$

where I is calculated according to D.3 of annex D.

D) Repeat the test specified in A) for a storage period of 30 days but store in a climatic chamber in which the temperature is 20 °C ± 2 °C and the relative humidity is 90 %.

Show that:

$$0{,}80 \leq \frac{\bar{E}\text{ (group 1, group 2)}}{C} \pm I \leq 1{,}20$$

where I is calculated according to D.3 of annex D.

8.6.5 *Detection threshold*

8.6.5.1 *Requirements*

The detection threshold shall not exceed:

- 0,5 mSv (50 mrem) for class P_e (7 mg · cm^{-2}) systems;
- 0,1 mSv (10 mrem) for class P_e (1 000 mg · cm^{-2}) systems;
- 10 µSv (1 mrem) for class E_n (all) (7 d) systems;
- 30 µSv (3 mrem) for class E_n (all) (30 d) systems.

8.6.5.2 *Test method* (TT, QT, RT)

Prepare and read out *n* dosemeters.

Determine the evaluated value *E* for each (unirradiated) dosemeter and calculate the mean of the evaluated values $\bar{E}$ and standard deviation $s_{\bar{E}}$ for all *n* dosemeters.

Show that:

$$t_n \cdot s_{\bar{E}} \leq H$$

where:

H	*Class*
0,5 mSv (50 mrem)	P_e (7 mg · cm^{-2})
0,1 mSv (10 mrem)	P_e (1 000 mg · cm^{-2})
10 µSv (1 mrem)	E_n (all) (7 d)
30 µSv (3 mrem)	E_n (all) (30 d)

and t_n is the Student's *t* for *n*-1 degrees of freedom (*n* = number of dosemeters used in the test). See annex D, table D.1 for values of t_n.

8.6.6 *Self-irradiation*

8.6.6.1 *Requirements*

After a storage period of 30 days, the zero point shall not exceed the following values:

- 0,5 mSv (50 mrem) for class P_e (7 mg · cm^{-2}) systems;
- 0,1 mSv (10 mrem) for class P_e (1 000 mg · cm^{-2}) systems;
- 30 µSv (3 mrem) for class E_n (all) systems.

If the irradiation time is increased by a factor of *x*, the reference values increase by the same factor and this can be useful to reduce the number of tests.

8.6.6.2 *Test method* (TT, QT)

Prepare *n* dosemeters.

Store them for 30 days under standard test conditions in a location where the background dose rate is known.

Read out the dosemeters and determine the evaluated value E.

Calculate the mean of the evaluated values $\bar{E}$ for all n dosemeters and its standard deviation. Determine the conventional true value, C_b (background), due to the background irradiation during storage.

Show that:

$$(\bar{E} + I) - C_b \leq H$$

where:

H	*Class*
0,5 mSv (50 mrem)	P_e (7 mg · cm^{-2})
0,1 mSv (10 mrem)	P_e (1 000 mg · cm^{-2})
30 µSv (3 mrem)	E_n (all)

where I is calculated according to D.3 of annex D. The uncertainties over C_b are considered negligible.

8.6.7 *Residue*

8.6.7.1 *Requirements*

After irradiation with a conventional true value of 100 mSv (10 rem) for all class P_e systems, the required detection threshold, as specified in 8.6.5, shall not be exceeded and the response shall not change by more than 10 % at a level of 2 mSv (200 mrem).

After irradiation with a conventional true value of 10 mSv (1 rem), for all class E_n systems, the required detection threshold, as specified in 8.6.5, shall not be exceeded and the response shall not change by more than 10 % at a level of 0,2 mSv (20 mrem).

8.6.7.2 *Test method* (TT)

A) Effect on detection threshold

Prepare, irradiate and read out the n dosemeters used for the detection threshold test (see 8.6.5). The conventional true value C shall be about 100 mSv (10 rem) for all class P_e systems and 10 mSv (1 rem) for all class E_n systems.

Using the same dosemeters, repeat the test for detection threshold (see 8.6.5).

B) Effect on response

Prepare, irradiate and read out the same n dosemeters used in A).

The conventional true value C shall be about 2 mSv (200 mrem) for all class P_e systems and about 0,2 mSv (20 mrem) for all class E_n systems.

Determine the evaluated value E for each dosemeter and calculate the mean of the evaluated values $\bar{E}$ and standard deviation, $s_{\bar{E}}$.

Show that:

$$0,90 \le \frac{\bar{E} \pm I}{C} \le 1,10$$

where I is calculated according to D.3 of annex D. Uncertainties over C are considered negligible.

NOTE - This test essentially limits any residue to a level of the order of 0,1 %.

8.6.8 *Effects of light exposure on the dosemeter*

8.6.8.1 *Requirements*

After exposure to 1 000 W · m^{-2} (see note) for 24 h the zero point shall not change by more than the required detection threshold and after exposure for one week the evaluated value shall not differ from the evaluated value of dosemeters kept in the dark by more than 10 %.

NOTE - To produce 1 000 W · m^{-2} of light, use an apparatus which produces light whose spectrum corresponds to that of bright sunlight (295 nm to 769 nm), e.g. a xenon lamp equipped, if necessary, with appropriate filters, or use a daylight fluorescent lamp.

8.6.8.2 *Test method* (TT, QT)

A) Effect on zero point

Prepare two groups of 20 dosemeters each.

Expose group 1 to 1 000 W · m^{-2} of light (see note to 8.6.8.1) for 24 h. (Ensure that the temperature of the dosemeters is maintained at less than 40 °C.)

Store the group 2 dosemeters in the dark in an otherwise identical environment. (Ensure that the temperature of group 2 dosemeters is within ±5 °C of the group 1 dosemeters.)

After one day, read out all dosemeters.

Determine the evaluated value E for each and calculate the mean of the evaluated values $\bar{E}$ for each of the two groups and their respective standard deviations.

Show that:

$$[\bar{E}\ (\text{group 1}) - \bar{E}\ (\text{group 2})] \pm I \le H$$

where I is calculated according to D.4 of annex D for the difference of two means,

where:

H	*Class*
500 µSv (50 mrem)	P_e (7 mg · cm^{-2})
100 µSv (10 mrem)	P_e (1 000 mg · cm^{-2})
10 µSv (1 mrem)	E_n (all) (7 d)
30 µSv (3 mrem)	E_n (all) (30 d)

B) Effect on response.

Prepare and irradiate two groups of 20 dosemeters each. The conventional true value *C* shall be about 10 mSv (1 rem) for class P_e (all) and class E_n (all) systems.

Expose and store groups 1 and 2 respectively as in A).

After 168 h read out all dosemeters.

Determine the evaluated value *E* for each and calculate the mean of the evaluated values ($\bar{E}$) for each of the two groups and their respective standard deviations.

Show that:

$$0{,}90 \leq \frac{\bar{E}\text{ (group 1)}}{\bar{E}\text{ (group 2)}} \pm I \leq 1{,}10$$

where *I* is calculated according to D.4 of annex D for the quotient of two means.

8.6.9 *Energy response (photons)*

8.6.9.1 *Requirements*

When irradiated with photons in the range 15 keV to 3,0 MeV for class P_e (all) dosemeters, and in the range 30 keV to 3,0 MeV for class E_n (30 keV) (all) dosemeters, the evaluated value shall not differ from the conventional true value by more than 30 %.

For class E_n (80 keV) (all) dosemeters, when irradiated with photons in the range 30 keV to 80 keV, the evaluated value shall not exceed the conventional true value by more than a factor of two and when irradiated with photons in the range 80 keV to 3,0 MeV, the evaluated value shall not differ from the conventional true value by more than 30 %.

8.6.9.2 *Test method* (TT)

A) All personal dosemeters and environmental dosemeters class E_n (30 keV) (all)

Prepare, irradiate and read out four groups of *n* dosemeters each. The conventional true value *C* for class P_e (all) and for class E_n (30 keV) (all) shall be about 10 mSv (1 rem), using the following radiation:

- group 1: 15,8 keV X-rays;
- group 2: reference radiation in range 30-40 keV;
- group 3: reference radiation in range 80-100 keV;
- group 4: ^{137}Cs or ^{60}Co.

Determine the evaluated value *E* for each dosemeter and calculate the mean of the evaluated values $\bar{E}$ for each of the four groups and the respective standard deviations.

For each group show that:

$$0{,}7 \leq \frac{\bar{E}_i \pm I_i}{C} \leq 1{,}3 \qquad (i = 1, 2, 3, 4)$$

where *I* is calculated according to D.3 of annex D. Uncertainties over *C* are considered negligible.

NOTES

1 Personal dosemeters should be irradiated on a phantom.

2 Group 1 energy should not be used for environmental dosemeters.

B) Environmental dosemeters, class E_n (80 keV) (all)

Perform the test as in A) for class E_n (30 keV) (all).

For group 2, show that:

$$\frac{\bar{E} + I}{C} \leq 2$$

For groups 3 and 4, show that:

$$0,7 \leq \frac{\bar{E}_i \pm I_i}{C} \leq 1,3 \qquad (i = 3, 4)$$

8.6.10 *Energy response (beta rays)*

8.6.10.1 *Requirements*

For class P_e (all) dosemeters, when irradiated with beta rays in the range (E_{max}) 0,5 MeV to 3 MeV, the response shall not vary by more than 30 %.

8.6.10.2 *Test method* (TT)

Prepare, irradiate and read out two groups of *n* dosemeters each. The conventional true value *C* shall be about 10 mSv (1 rem) using the following:

- group 1: $^{90}Sr/^{90}Y$;
- group 2: ^{204}Tl.

Determine the evaluated value *E* for each dosemeter and calculate the mean of the evaluated values $\bar{E}$ for each of the two groups.

For each group, show that:

$$0,7 \leq \frac{\bar{E}_i \pm I_i}{C} \leq 1,3 \qquad (i = 1, 2)$$

8.6.11 *Isotropy (photons)*

8.6.11.1 *Requirements*

For P_e (all) dosemeters irradiated with photons of 60 ± 5 keV, the mean value of the responses at angles of incidence of 20°, 40° and 60° from normal shall not differ from the corresponding response for normal incidence by more than 15 %.

For E_n (all) dosemeters irradiated with ^{60}Co or ^{137}Cs while being rotated around three perpendicular axes using the centre of the dosemeter as the centre of rotation, the response shall not vary by more than 15 %.

8.6.11.2 *Test method* (TT)

A) Personal dosemeters

Prepare, irradiate on a phantom and read out four groups of dosemeters. Let n_i be the number of dosemeters of the i-th group. The conventional true value C shall be about 10 mSv (1 rem) using photons of energy (60 ± 5) keV (X-rays or ^{241}Am) and the following conditions:

- group 1: normal incidence;
- group 2: 20° off normal;
- group 3: 40° off normal;
- group 4: 60° off normal.

The angle of incidence is varied in two planes perpendicular to each other and to the plane of the dosemeter adjacent to the phantom. More than one irradiation at each angle can be undertaken simultaneously on a sphered phantom.

Determine the evaluated value E for each dosemeter and calculate the mean of the evaluated values $\bar{E}$ for each of the four groups and the respective standard deviations $s_{\bar{E}}$.

Show that:

$$0{,}85 \leq \frac{\sum_{i=1}^{4} \bar{E}_i}{4\bar{E}_i} \pm I \leq 1{,}15$$

where I is determined according to D.4 of annex D.

B) Environmental dosemeters

Prepare, irradiate and read out three groups of n dosemeters each. The conventional true value C shall be about 10 mSv (1 rem) using ^{60}Co or ^{137}Cs. During irradiation, each dosemeter in each group shall be rotated around one of three perpendicular axes using the centre of the dosemeter as the centre of rotation.

Determine the evaluated value E for each dosemeter of each group and calculate the mean of the evaluated values $\bar{E}$ and the respective standard deviations $s_{\bar{E}}$ for each group.

Show that, for each group:

$$0{,}85 \leq \frac{\bar{E} \pm I_i}{C} \leq 1{,}15 \qquad (i = 1, 2, 3)$$

where I is determined according to D.3 of annex D.

8.6.12 *Primary power supply voltage and frequency*

8.6.12.1 *Requirements*

For all classes, the evaluated value of dosemeters read out under steady conditions of high or low voltage/frequency shall not differ from the evaluated value of dosemeters read out under normal reader operating conditions by more than 5 %.

8.6.12.2 *Test method* (TT)

Prepare and irradiate five groups of dosemeters. Let n_i be the number of dosemeters of the *i*-th group. The conventional true value *C* shall be about 10 mSv (1 rem).

Read out the dosemeters under the following conditions:

- group 1: normal reader operation;
- group 2: voltage 12 % low and frequency 2 % low;
- group 3: voltage 10 % high and frequency 2 % low;
- group 4: voltage 10 % high and frequency 2 % high;
- group 5: voltage 12 % low and frequency 2 % high.

Determine the evaluated value *E* for each dosemeter and calculate the mean of the evaluated values $\bar{E}$ for each group and the respective standard deviations.

Show that for groups 2 to 5:

$$0{,}95 \leq \frac{\bar{E}\ (\text{group } x)}{\bar{E}\ (\text{group } 1)} \pm I \leq 1{,}05 \qquad (x = 2, 3, 4, 5)$$

where *I* is calculated in accordance with D.4 of annex D.

8.6.13 *Transient voltage*

8.6.13.1 *Requirements*

For all classes, the evaluated value of dosemeters read out following voltage transients shall not differ from the evaluated value of dosemeters read out under normal reader operating conditions by more than 5 %.

8.6.13.2 *Test method* (TT)

Prepare and irradiate three groups of *n* dosemeters. Let n_i be the number of dosemeters of the *i*-th group. The conventional true value *C* shall be about 10 mSv (1 rem). Read out all the dosemeters in each group respectively under the following conditions:

- group 1: normal reader operation;
- group 2: after a transient decrease (initial voltage 10 % below nominal, 1 s decrease to 20 % below nominal held for 1 s, return to 10 % below nominal in 2 s);
- group 3: after a transient increase (initial voltage 10 % above nominal, 1 s increase to 20 % above nominal held for 1 s, return to 10 % above nominal in 2 s).

Determine the evaluated value *E* for each dosemeter and calculate the mean of the evaluated values $\bar{E}$ for each group and the respective standard deviations.

Show that for groups 2 and 3:

$$0{,}95 \leq \frac{\bar{E}\ (\text{group } x)}{\bar{E}\ (\text{group } 1)} \pm I \leq 1{,}05 \qquad (x = 2,\ 3)$$

where I is calculated according to D.4 of annex D.

8.6.14 *Effects of climatic conditions on the reader*

8.6.14.1 *Requirements*

For all classes, the reader background shall not vary by more than 20 % of the required detection threshold and the evaluated values shall not differ from the evaluated values determined under normal conditions by more than 10 % after and during exposure of the reader to the temperature and humidity conditions reported in the test (see A) and B) below).

8.6.14.2 *Test method* (TT)

A) Effects on reader background

Perform nine groups of readout cycles. Let n_i be the number of cycles performed in the i-th group. Each readout cycle shall be performed without a detector or a dosemeter* in the reader under the following conditions:

- group 1: normal reader operation;
- group 2: after reader exposure to +60 °C and 65 % RH;
- group 3: during reader exposure to +35 °C and 65 % RH;
- group 4: after reader exposure to -10 °C and 65 % RH;
- group 5: during reader exposure to +10 °C and 65 % RH;
- group 6: after reader exposure to +20 °C and 90 % RH;
- group 7: during reader exposure to +20 °C and 90 % RH;
- group 8: after reader exposure to +20 °C and 5 % RH;
- group 9: during reader exposure to +20 °C and 5 % RH.

Determine the evaluated value E for each readout and calculate the mean of the evaluated values $\bar{E}$ for each group and its standard deviation.

Show that for groups 2 to 9:

$$[\bar{E}\ (\text{group } x) - \bar{E}\ (\text{group } 1)] \pm I \leq 0{,}2 \times H_{\max}\ (x = 2 \text{ to } 9)$$

where $H_{\max}$ is the required detection threshold (see 8.6.5) for the class being tested and I is determined according to the methods of D.4 of annex D.

If the reader cannot be operated without a dosemeter or a detector, a dummy may be substituted.

B) Effects on response

Prepare and irradiate nine groups of dosemeters. Let n_i be the number of dosemeters of the *i*-th group. The conventional true value *C* shall be about 10 mSv (1 rem).

Read out the dosemeters under the following conditions:

- group 1: normal reader operation;
- group 2: after reader exposure to +60 °C and 65 % RH;
- group 3: during reader exposure to +35 °C and 65 % RH;
- group 4: after reader exposure to -10 °C and 65 % RH;
- group 5: during reader exposure to +10 °C and 65 % RH;
- group 6: after reader exposure to +20 °C and 90 % RH;
- group 7: during reader exposure to +20 °C and 90 % RH;
- group 8: after reader exposure to +20 °C and 5 % RH;
- group 9: during reader exposure to +20 °C and 5 % RH.

Determine the evaluated value *E* for each readout and calculate the mean of the evaluated values $\bar{E}$ for each group and its standard deviation.

Show that for groups 2 to 9:

$$0{,}90 \le \frac{\bar{E}\text{ (group } x)}{\bar{E}\text{ (group 1)}} \pm I \le 1{,}10 \qquad (x = 2 \text{ to } 9)$$

where *I* is determined according to D.4 of annex D.

NOTE - The test conditions should be achieved by using a climatic test chamber as follows:

1) For readouts after climatic exposure

Temperature - Place the reader (without dosemeters or detectors and without power applied) in the climatic chamber under standard conditions. Raise or lower the temperature at a rate of ≥15 $°\mathrm{C.h^{-1}}$.

Maintain the required temperature for 2 h. Return the temperature at a rate of ≥15 $°\mathrm{C.h^{-1}}$ to standard conditions. Maintain the reader in the chamber under standard conditions for 6 h before testing.

Humidity - Place the reader (without dosemeters or detectors and without power applied) in the climatic chamber under the humidity conditions required for 24 h. Remove the reader and after 1 h, apply power. Maintain the reader under standard conditions for 6 h before testing.

2) For readouts during climatic exposure

Temperature - Place the reader (with power applied) in the climatic chamber under standard test conditions. Raise or lower the temperature at a rate ≥15 $°\mathrm{C.h^{-1}}$. Maintain the required temperature for 2 h. Perform the readouts in the chamber under these conditions, introducing any dosemeters just prior to readout.

Humidity - Place the reader (with power applied) in the climatic chamber under the required humidity conditions. Maintain these conditions for 6 h. Perform the readouts in the chamber under these condition introducing any dosemeters just prior to readout.

8.6.15 *Effects of vibration on the reader*

8.6.15.1 *Requirements*

For all classes, the evaluated value of dosemeters read out following exposure of the reader to sinusoidal vibration shall not differ from the evaluated value following readout under normal reader conditions by more than 5 %.

8.6.15.2 *Test method* (TT)

Prepare and irradiate two groups of dosemeters. Let n_i be the number of dosemeters of each group. The conventional true value *C* shall be about 10 mSv (1 rem).

Read out the dosemeters under the following conditions:

- group 1: normal reader operation;
- group 2: after reader exposure to vibration (see note below).

Determine the evaluated value *E* for each dosemeter and calculate the mean of the evaluated values $\bar{E}$ for each group and its standard deviation.

Show that:

$$0{,}95 \leq \frac{\bar{E}\ (\text{group 2})}{\bar{E}\ (\text{group 1})} \pm I \leq 1{,}05$$

where *I* is determined according to D.4 of annex D.

NOTE - The test conditions should be achieved as follows: with the reader mounted in its normal orientation, it is vibrated (displacement in the vertical direction) sinusoidally for 1 h at a frequency of 50 Hz and a peak-to-peak amplitude of 1 mm. The instrument should be mounted in such a way as to minimize the generation of alternative modes of vibration.

8.6.16 *Dropping effect on dosemeter*

8.6.16.1 *Requirements*

For all classes, the evaluated value of dosemeters readout being dropped 1 m onto a concrete surface shall not differ from the evaluated value under normal conditions by more than 10 %.

8.6.16.2 *Test method* (TT)

Prepare and irradiate two groups of dosemeters. Let n_i be the number of dosemeters of each group. The conventional true value *C* shall be about 10 mSv (1 rem). Read out the dosemeters under the following conditions:

- group 1: normal operation;
- group 2: after dropping the dosemeters 1 m onto a concrete surface.

Determine the evaluated value *E* for each dosemeter and calculate the mean of the evaluated values $\bar{E}$ for each group and its standard deviation.

Show that:

$$0{,}90 \leq \frac{\bar{E}\ (\text{group 2})}{\bar{E}\ (\text{group 1})} \pm I \leq 1{,}10$$

where I is determined according to D.4 of annex D.

8.6.17 *Dropping effect on reader*

8.6.17.1 *Requirements*

For all classes, the evaluated value of dosemeters read out following dropping the reader 1 cm onto a wood surface shall not differ from the evaluated value under normal reader conditions by more than 5 %.

8.6.17.2 *Test method* (TT)

Prepare and irradiate two groups of dosemeters. Let n_i be the number of dosemeters of each group. The conventional true value C shall be about 10 mSv (1 rem).

Read out the dosemeters under the following conditions:

- group 1: normal reader operation;
- group 2: after dropping the reader 1 cm onto a wood surface simulating possible drop during operation.

Determine the evaluated value E for each dosemeter and calculate the mean of the evaluated values $\bar{E}$ for each group and its standard deviation.

Show that:

$$0{,}95 \leq \frac{\bar{E}\ (\text{group 2})}{\bar{E}\ (\text{group 1})} \pm I \leq 1{,}05$$

where I is determined according to D.4 of annex D.

8.6.18 *Effects of reader light leakage*

8.6.18.1 *Requirements*

For all classes, the reader background shall not vary by more than 20 % of the required detection threshold when the reader is exposed to 1 000 $\text{W} \cdot \text{m}^{-2}$ of light.

8.6.18.2 *Test method* (RT)

Perform two groups of readout cycles. Let n_i be the number of cycles performed in the i-th group. Each cycle shall be performed without a detector or a dosemeter in the reader under the following conditions:

- group 1: normal reader operation;
- group 2: during reader exposure to 1 000 $\text{W} \cdot \text{m}^{-2}$ (over 4 π, except base) (see note of 8.6.8.1 for conditions).

Determine the mean evaluated value $\bar{E}$ for each group and the respective standard deviations.

Show that:

$$[\bar{E} \text{ (group 2)} - \bar{E} \text{ (group 1)}] \pm I \leq 0{,}2 \times H_{max}$$

where H_{max} is the detection threshold for the class being tested and I is determined according to D.4 of annex D.

8.7 *Requirements and test methods for TL readers*

8.7.1 *General*

For all classes of readers, the evaluated values E and the conventional true values C may be expressed in terms of kerma in air.

Tests may be performed with either dosemeters or detectors.

The requirements and test methods for TL readers are those given in 8.6.12 to 8.6.17.2 except 8.6.14.2.

8.7.2 *Reader stability*

8.7.2.1 *Requirements*

The evaluated values of dosemeters read out 24 h apart and 168 h apart shall not differ from each other by more than 5 % and 10 %, respectively.

8.7.2.2 *Test method* (RT)

Prepare and irradiate three groups of dosemeters. Let n_i be the number of dosemeters of the i-th group. The conventional true value C shall be about 10 mGy (1 rad) for both P_e (all) and E_n (all) systems.

Store all groups for two weeks under standard conditions. Read out group 1 and use the results to determine the evaluation factor F_e. Read out the remaining dosemeters under the following conditions:

- group 2: 24 h after the readout of group 1;
- group 3: 168 h after the readout of group 1.

Determine the evaluated value E for each dosemeter using the evaluation factor F_e determined with group 1, and calculate the mean of the evaluated values $\bar{E}$ for each group and the respective standard deviations.

Show that:

$$0{,}95 \leq \frac{\bar{E}\ (\text{group 2})}{\bar{E}\ (\text{group 1})} \pm I \leq 1{,}05$$

$$0{,}90 \leq \frac{\bar{E}\ (\text{group 3})}{\bar{E}\ (\text{group 1})} \pm I \leq 1{,}10$$

where I is determined according to D.4 of annex D.

8.8 *Requirements and test methods for TL detectors*

8.8.1 *General*

For all classes of detectors, evaluated values E and conventional true values C may be expressed in terms of kerma in air.

8.8.2 *Batch homogeneity*

8.8.2.1 *Requirements*

For all classes, the evaluated value for any one detector in a batch shall not differ from the evaluated value for any other detector in the batch by more than 30 % for a dose equal to ten times the required detection threshold limit.

8.8.2.2 *Test method* (RT)

Prepare and irradiate all the detectors in the batch to the same conventional true value C to a dose equal to ten times the required detection threshold limit.

Determine the evaluated value E for each detector and identify the detectors with the maximum and minimum evaluated doses.

Show that:

$$\frac{E_{\max} - E_{\min}}{E_{\min}} \leq 0{,}3$$

8.8.3 *Reproducibility*

8.8.3.1 *Requirements*

The coefficient of variation of the evaluated value shall not exceed 7,5 % for a dose of:

- 10 mGy (1 rad) for class P_e (all);
- 50 µGy (5 mrad) for class E_n (all) (7 d);
- 200 µGy (20 mrad) for class E_n (all) (30 d).

8.8.3.2 *Test method* (TT, QT)

Prepare, irradiate and read out each of n detectors. Repeat this 10 times. The conventional true value C shall be exactly the same each time and about:

- 10 mGy (1 rad) for all class P_e detectors;
- 50 µGy (5 mrad) for class E_n (7 d) detectors;
- 200 µGy(20 mrad) for class E_n (30 d) detectors.

For each detector, determine E_{ji} where j refers to the j-th detector and i to the i-th irradiation.

For each of the 10 irradiations, calculate the mean $\bar{E}_i$ and standard deviation $s_{\bar{E}i}$.

Show that:

$$\frac{s_{\bar{E}i} + I_i}{\sum_{i=1}^{10} \bar{E}_i / 10} \leq 0{,}075$$

where I_i, confidence interval of $s_{\bar{E}i}$, is calculated according to D.2 of annex D.

For each of the n detectors, determine E_j and the mean value:

$$\bar{E}_j = \frac{1}{10} \sum_{i=1}^{10} E_{ij}$$

and the standard deviation $s_{\bar{E}j}$.

Show that for each of the n detectors:

$$\frac{s_{\bar{E}j} + I_j}{\bar{E}_j} \leq 0{,}075$$

where I_j, confidence interval of $s_{\bar{E}j}$, is calculated according to D.2 of annex D.

8.9 *Information requested for TL detectors*

8.9.1 *Linearity*

The evaluated value (and standard deviation) relative to the conventional true value shall be given over the range:

- 0,1 mGy to 1 Gy (0,01 rad to 100 rad) for P_e (all) classes;
- 0,03 mGy to 0,1 Gy (3 mrad to 10 rad) for E_n (all) classes.

8.9.2 *Procedure* (TT, QT)

Prepare, irradiate and read out five groups of n detectors each. The conventional true values C for groups 1; 2; 3; 4 and 5 shall be 0,1; 1; 10 and 100 mGy, and 1 Gy (0,01; 0,1; 1; 10 and 100 rad) for all class P_e detectors, and 0,03; 0,1; 1; 10 and 100 mGy (3, 10 and 100 mrad; and 1; 10 rad) for all class E_n detectors.

Calculate the mean $\bar{E}$ and standard deviation $s_{\bar{E}}$ of the evaluated values for each group.

Information required for each group:

$$\frac{\bar{E}\ (\text{group } x)}{C}\ ;\ I\ (\text{group } x)\quad (x = 1, 2, 3, 4, 5)$$

8.9.3 *Energy response (photons)*

For all classes, the evaluated value (and standard deviation) relative to the conventional true value shall be given over the range 15 keV to 3 MeV.

8.9.4 *Procedure* (TT)

Prepare, irradiate and read out four groups of *n* detectors each. The conventional true value (*C*) shall be about 10 mGy (1 rad). Read out the dosemeters under the following conditions:

- group 1: 15,8 keV X-rays;
- group 2: reference radiation in the range 30 keV to 40 keV;
- group 3: reference radiation in the range 80 keV to 100 keV;
- group 4: ^{137}Cs or ^{60}Co.

Determine the evaluated value *E* for each detector and calculate the mean $\bar{E}$ and standard deviation $s_{\bar{E}}$ of the evaluated values for each of the four groups.

Information required for each group:

$$\frac{\bar{E}\ (\text{group } x)}{C}\ ;\ I\ (\text{group } x)\quad (x = 1, 2, 3, 4)$$

NOTES

1 All irradiations should be free in air; for ^{137}Cs and ^{60}Co, additional provision should be made for electron equilibrium.

2 Group 1 energy should not be used for detectors intended to be used as environmental dosemeters.

8.9.5 *Effects of light exposure on the detector*

For all classes, the zero point (and standard deviation) for detectors exposed to 1 000 W · m^{-2} for one day and the response after one week shall be given relative to those for detectors kept in the dark under conditions otherwise identical.

8.9.6 *Procedure* (TT)

8.9.6.1 *Effect on zero point*

Prepare two groups of 20 detectors each.

Expose group 1 to 1 000 W · m^{-2} of light (see note to 8.6.8.1) for 24 h (ensure that the temperature of detectors is maintained at less than 40 °C).

Store the group 2 detectors in the dark in an otherwise identical environment (the temperature of group 2 detectors shall be within ±5 °C of the group 1 detectors).

After one day, read out all detectors.

Determine the evaluated value E for each and calculate the mean $\bar{E}$ and standard deviation $s_{\bar{E}}$ of the evaluated doses for each of the two groups.

Information required:

$\bar{E}$ (group 1) - $\bar{E}$ (group 2); I (group 1); I (group 2)

8.9.6.2 *Effect on response*

Prepare and irradiate two groups of 20 detectors each.

The conventional true value C shall be about 10 mGy (1 rad).

Expose and store groups 1 and 2, respectively, as in 8.9.6.1.

After one week, read out all detectors.

Determine the evaluated value E for each and calculate the mean $\bar{E}$ and standard deviation $s_{\bar{E}}$ of the evaluated values for each of the two groups.

Information required:

$\bar{E}$ (group 1) / $\bar{E}$ (group 2); I (group 1); I (group 2).

9 Certification

TLD systems, detectors, and readers tested for compliance with this standard as specified in clause 8 shall be accompanied by a certificate which shall contain the following information:

a) manufacturer's name and address;

b) name and address of facility at which tests were performed;

c) date on which tests were performed;

d) type, serial or identification number and description of each component tested or used for testing;

e) description of additional equipment and procedures (including correction procedures and conversion factors) used during testing (see 1 to 7 and annex C);

f) class (or classes) tested;

g) statement indicating the results of the performance tests and, in the case of detectors tested separately, providing the information required in table 3.

10 Power supply

Mains operated readers shall be designed to operate from single phase supply in one of the following categories:

- *category* 1: 220 V;
- category 2: 120 V and/or 240 V.

11 Instructions

The manufacturer shall supply sufficient written instructions to allow the user to obtain performance within the requirements of this standard.

Table 4 - Reference conditions and standard test conditions

Influence quantity	Reference conditions (unless otherwise stated by the manufacturer)	Standard test conditions (unless otherwise stated by the manufacturer)
Reference photon radiation	To conform to ISO 4037	To conform to ISO 4037
Reference beta radiation	To conform to ISO 6980	To conform to ISO 6980
Warm-up time	30 min	≥30 min
Ambient temperature	20 °C	18 °C to 22 °C
Atmospheric pressure	101,3 kPa	86 kPa to 106 kPa
Relative humidity	65%	50 % to 65 %
Power supply voltage	Nominal supply voltage U_N	Nominal supply voltage U_N ±1%
Power supply frequency	Nominal frequency	Nominal frequency ±1 %
Power supply waveform	Sinusoidal	Sinusoidal with total harmonic distortion lower than 5 %
Gamma radiation background	0,20 $\mu Gy \cdot h^{-1}$	0,20 $\mu Gy \cdot h^{-1}$
Electromagnetic field of external origin	Negligible	Less than the lowest value that causes interference
Magnetic induction of external origin	Negligible	Less than twice the value of the induction due to the earth's magnetic field
Assembly controls	Set for normal operation	Set for normal operation
Contamination by radioactive elements	Negligible	Negligible
Light intensity	50 $W \cdot m^{-2}$	<1 000 $W \cdot m^{-2}$

Annex A

Dose equivalent conversion factors for personal dosemeters

Personal dosemeters should be calibrated in terms of dose equivalent in tissue:

- at a depth of 7 $\text{mg} \cdot \text{cm}^{-2}$;
- at a depth of 1 000 $\text{mg} \cdot \text{cm}^{-2}$.

For calibration, the dosemeters should be irradiated on a phantom at various photon energies between 15 keV and 3 MeV. The evaluated value E, for each class of systems and for each photon energy chosen, shall be compared with the conventional true value C in the phantom at the appropriate depth.

When the photon source is calibrated in terms of kerma in air K_a at electronic equilibrium without a receptor and the dosemeters are irradiated with phantom backing, then:

$$C\,(7\ \text{mg} \cdot \text{cm}^{-2}) = F_c\,(7\ \text{mg} \cdot \text{cm}^{-2}) \cdot K_a$$

$$C\,(1\,000\ \text{mg} \cdot \text{cm}^{-2}) = F_c\,(1\,000\ \text{mg} \cdot \text{cm}^{-2}) \cdot K_a$$

where F_c (7 $\text{mg} \cdot \text{cm}^{-2}$) and F_c (1 000 $\text{mg} \cdot \text{cm}^{-2}$) are the conversion factors for the two depths. Numerical values for the conversion factors for the two classes of personal dosemeters (7 $\text{mg} \cdot \text{cm}^{-2}$ and 1 000 $\text{mg} \cdot \text{cm}^{-2}$, respectively), for one possible phantom (30 cm diameter ICRU sphere), for parallel beam geometry and for various angles of incidence are given in tables A.1 to A.12. Intermediate values can be obtained by interpolation. These tables are only examples of the conversion factors that are available.

Until relevant international bodies publish recommendations on the conversion factors to be used, the proposed examples taken from various publications may be used by agreement between the parties using the standard.

NOTE - Other phantoms are not excluded, provided that relevant information is made available.

Table A.1 - Conversion of air kerma to directional dose equivalent $H'(0,07)$ for monoenergetic photons of energy E

E keV	$H'(0,07)/K_a$ Sv · Gy^{-1}
10	0,95
15	0,99
20	1,05
25	1,13
30	1,22
40	1,41
50	1,53
60	1,59
70	1,61
80	1,61
90	1,58
100	1,55
125	1,48
150	1,42
200	1,34
250	1,32

From: "New Quantities in Radiation Protection and Conversion Coefficients", *Rad. Prot. Dosimetry* 14 (4), pp. 337-343 (1986).

Table A.2 - Conversion of air kerma to directional dose equivalent $H'(10)$ for photons

Series	Mean energy keV	$H'(10)/K_a$ Sv/Gy
Filtered X reference radiations Narrow spectrum	33	1,197
	48	1,599
	65	1,734
	83	1,707
	100	1,646
	118	1,587
	161	1,466
	205	1,395
	248	1,349
Filtered X reference radiations Wide spectrum	45	1,537
	58	1,677
	79	1,709
	104	1,632
	134	1,536
	169	1,454
	202	1,402
Zirconium K-fluorescence reference radiation	15,8	0,365
Cesium-137	662	1,196
Cobalt-60	1 250	1,151

From: S. Wagner *et al.*: *Rad. Prot. Dosimetry* 12, p. 231 (1985), and Grosswendt *et al.*: *Rad. Prot. Dosimetry* 3, p. 169 (1982).

Table A.3 - Conversion of air kerma to directional dose equivalent $H'(0,07)$ for photons

Series	Mean energy keV	$H'(0,07)/K_a$ Sv/Gy
Filtered X reference radiations Narrow spectrum	33	1,271
	48	1,492
	65	1,598
	83	1,595
	100	1,553
	118	1,502
	161	–
	205	–
	248	–
Filtered X reference radiations Wide spectrum	45	1,456
	58	1,552
	79	1,591
	104	1,537
	134	–
	169	–
	202	–
Zirconium K-fluorescence reference radiation	15,8	0,999
Cesium-137	662	
Cobalt-60	1 250	

From: S. Wagner *et al.*: *Rad. Prot. Dosimetry* 12, p. 231 (1985), and Grosswendt *et al.*: *Rad. Prot. Dosimetry* 3, p. 169 (1982).

Table A.4 - Conversion of air kerma to directional dose equivalent $H'(0,07)$ for different angles of incidence

Series	Mean energy keV	$H'(0,07)/K_a$ (Sv/Gy) for the angle of incidence			
		0°	20°	40°	60°
Filtered X reference radiations Narrow spectrum	33	1,271	1,263	1,222	1,131
	48	1,492	1,483	1,452	1,372
	65	1,598	1,588	1,564	1,496
	83	1,595	1,585	1,567	1,509
	100	1,553	1,543	1,530	1,483
	118	1,501	1,493	1,485	1,448
	161	–	–	–	–
	205	–	–	–	–
	248	–	–	–	–
Filtered X reference radiations Wide spectrum	45	1,456	1,447	1,414	1,333
	58	1,552	1,543	1,515	1,442
	79	1,591	1,581	1,562	1,502
	104	1,537	1,528	1,516	1,471
	134	–	–	–	–
	169	–	–	–	–
	202	–	–	–	–
Zirconium, K-fluorescence reference radiation	15,8	0,999	0,983	0,928	0,724
Cesium-137	662				
Cobalt-60	1 250				

From: S. Wagner *et al.*: *Rad. Prot. Dosimetry* 12, p. 231 (1985), and Grosswendt *et al.* *Rad. Prot. Dosimetry* 3, p. 169 (1982).

Table A.5 - Conversion of air kerma to directional dose equivalent $H'(10)$ for different angles of incidence

Series	Mean energy keV	$H'(10)/K_a$ (Sv/Gy) for the angle of incidence			
		0°	20°	40°	60°
Filtered X reference radiations Narrow spectrum	33	1,197	1,167	1,061	0,857
	48	1,599	1,577	1,472	1,264
	65	1,734	1,715	1,624	1,430
	83	1,707	1,690	1,616	1,442
	100	1,646	1,631	1,569	1,414
	118	1,587	1,574	1,520	1,383
	161	1,466	1,457	1,416	1,311
	205	1,395	1,388	1,353	1,263
	248	1,349	1,344	1,312	1,232
Filtered X reference radiations Wide spectrum	45	1,537	1,514	1,408	1,200
	58	1,677	1,657	1,559	1,358
	79	1,709	1,692	1,613	1,435
	104	1,632	1,617	1,555	1,404
	134	1,536	1,524	1,476	1,352
	169	1,454	1,445	1,405	1,301
	202	1,402	1,395	1,359	1,268
Zirconium, K-fluorescence reterence radiation	15,8	0,365	0,309	0,210	0,097
Cesium-137	662	1,196	1,196	1,184	1,142
Cobalt-60	1 250	1,151	1,151	1,145	1,111

From: S. Wagner *et al.*: *Rad. Prot. Dosimetry* 12, p. 231 (1985), and Grosswendt *et al.*: *Rad. Prot. Dosimetry* 3, p. 169 (1982).

Table A.6 - Conversion of air kerma to directional dose equivalent $H'(0,07)$ for beta radiation

Maximum beta radiation energy MeV	$H'(0,07)/K_a$ Sv/Gy
0,1	0,10
0,15 (^{147}Pm)	0,22
0,2	0,40
0,3	0,72
0,4	1,00
0,5	1,16
0,57 (^{204}Tl)	1,22
0,6	1,23
0,7	1,24
0,8	1,25
0,9	1,25
1,0	1,25
1,5	1,25
2,0 (^{90}Sr + ^{90}Y)	1,25

From: "New Quantities in Radiation Protection and Conversion Coefficients", *Rad. Prot. Dosimetry* 14 (4), pp. 337-343 (1986).

Table A.7 - Conversion of air kerma to directional dose equivalent $H'(0,07)$ for photons

Series	Mean energy keV	$H'(0,07)/K_a$ Sv/Gy
Filtered X reference radiations Narrow spectrum	33	1,27
	48	1,53
	65	1,60
	83	1,60
	100	1,53
	118	1,48
	161	1,40
	205	1,34
	248	1,31
Filtered X reference radiations Wide spectrum	45	1,46
	58	1,59
	79	1,59
	104	1,53
	134	1,45
	169	1,39
	202	1,34
Zirconium K-fluorescence reference radiation	15,8	1,00
Cesium-137	662	1,18
Cobalt-60	1 250	1,14

From: G. Williams, W.P. Swanson, P. Kragh and G. Dexler: "Calculation and Analysis of Photon Dose Equivalent Distribution in the ICRU Sphere", *GSF Report S-958*, ISSN 0721-1694 (1985).

Table A.8 - Conversion of air kerma to directional dose equivalent $H'(10)$ for photons

Series	Mean energy keV	$H'(10)/K_a$ Sv/Gy
Filtered X reference radiations **Narrow spectrum**	33	1,23
	48	1,67
	65	1,78
	83	1,73
	100	1,63
	118	1,55
	161	1,45
	205	1,39
	248	1,35
Filtered X reference radiations **Wide spectrum**	45	1,57
	58	1,77
	79	1,76
	104	1,61
	134	1,50
	169	1,44
	202	1,39
Zirconium K-fluorescence reference radiation	15,8	0,36
Cesium-137	662	1,18
Cobalt-60	1 250	1,13

From: G. Williams, W.P. Swanson, P, Kragh and G. Dexler: "Calculation and Analysis of Photon Dose Equivalent Distribution in the ICRU Sphere". *GSF Report S-598,* ISSN 0721-1694 (1985).

Table A.9 - Conversion of air kerma to directional dose equivalent $H'(0,07)$ for different angles of incidence

Series	Mean energy keV	$H'(0,07)/K_a$ (Sv/Gy) for the angle of incidence			
		0°	20°	40°	60°
Filtered X reference radiations Narrow spectrum	33	1,27	1,28	1,26	1,21
	48	1,53	1,56	1,53	1,47
	65	1,60	1,64	1,60	1,54
	83	1,60	1,62	1,60	1,54
	100	1,53	1,56	1,55	1,51
	118	1,48	1,50	1,50	1,48
	161	1,40	1,41	1,42	1,42
	205	1,34	1,35	1,36	1,37
	248	1,31	1,31	1,31	1,33
Filtered X reference radiations Wide spectrum	45	1,46	1,49	1,47	1,40
	58	1,59	1,64	1,59	1,53
	79	1,59	1,62	1,60	1,55
	104	1,53	1,54	1,54	1,50
	134	1,45	1,46	1,47	1,46
	169	1,39	1,40	1,40	1,41
	202	1,34	1,36	1,36	1,37
Zirconium, K-fluorescence reference radiation	15,8	1,00	0,99	0,99	0,99
Cesium-137	662	1,18	1,18	1,19	1,20
Cobalt-60	1 250	1,14	1,14	1,15	1,17

From: G. Williams, W.P. Swanson, P. Kragh and G. Dexler: "Calculation and Analysis of Photon Dose Equivalent Distribution in the ICRU Sphere", *GSF Report S-958*, ISSN 0721-1694 (1985).

Table A.10 - Conversion of air kerma to directional dose equivalent $H'(10)$ for different angles of incidence

Series	Mean energy keV	$H'(10)/K_a$ (Sv/Gy) for the angle of incidence			
		0°	20°	40°	60°
Filtered X reference radiations Narrow spectrum	33	1,23	1,19	1,11	0,97
	48	1,67	1,68	1,57	1,40
	65	1,78	1,73	1,67	1,50
	83	1,73	1,69	1,66	1,50
	100	1,63	1,64	1,60	1,47
	118	1,55	1,57	1,54	1,42
	161	1,45	1,47	1,44	1,35
	205	1,39	1,38	1,37	1,31
	248	1,35	1,34	1,33	1,28
Filtered X reference radiations Wide spectrum	45	1,57	1,55	1,47	1,29
	58	1,77	1,75	1,65	1,49
	79	1,76	1,71	1,68	1,51
	104	1,61	1,61	1,59	1,45
	134	1,50	1,53	1,50	1,39
	169	1,44	1,45	1,42	1,34
	202	1,39	1,39	1,38	1,32
Zirconium K-fluorescence reference radiation	15,8	0,36	0,31	0,25	0,14
Cesium-137	662	1,18	1,18	1,17	1,16
Cobalt-60	1 250	1,13	1,13	1,13	1,12

From: G. Williams, W.P. Swanson, P. Kragh and G. Dexler: "Calculation and Analysis of Photon Dose Equivalent Distribution in the ICRU Sphere", *GSF Report S-958*, ISSN 0721-1694 (1985).

Table A.11 - Conversion coefficients for directional dose equivalent $H'(0{,}07)$ per unit fluence

Photon energy keV	Conversion coefficients 10^{-12} Sv · cm^2			
	0°	30°	60°	90°
10	6,83	6,82	6,47	1,50
15	3,08	3,05	2,97	1,31
20	1,73	1,73	1,69	1,02
25	1,18	1,16	1,12	0,759
30	0,872	0,862	0,830	0,572
40	0,585	0,583	0,556	0,412
50	0,481	0,483	0,464	0,345
75	0,469	0,464	0,450	0,360
100	0,579	0,569	0,554	0,455
150	0,849	0,849	0,852	0,739
250*	1,46	1,47	1,50	1,35
400*	2,35	2,36	2,42	2,24
662*	3,76	3,78	3,84	3,59
1 000*	5,25	5,31	5,39	5,14
1 250*	6,34	6,25	6,38	6,05

* These values are not for the surface shell, but for the next inner shell i.e. between 14,95 cm and 14,85 cm where electron equilibrium is attained. Treat values with caution.

From: P.J. Dimbylow and D.T. Bartlett: Personal communication (1986), and P.J. Dimbylow and T.M. Francis: "A Calculation of Photon Depth-Dose Distribution in the ICRU Sphere for a Broad Parallel Beam, a Point Source and an Isotropic Field", *NRPB R-92* (1979).

Table A.12 - Conversion coefficients for directional dose equivalent $H'(10)$ per unit fluence

Photon energy keV	Conversion coefficients 10^{-12} Sv · cm^2			
	0°	30°	60°	90°
10	0,0708	0,0392	0,00242	$<10^{-5}$
15	0,827	0,684	0,274	0,00443
20	1,00	0,932	0,604	0,0727
25	0,906	0,868	0,657	0,172
30	0,773	0,746	0,609	0,223
40	0,608	0,587	0,498	0,242
50	0,518	0,508	0,436	0,239
75	0,505	0,497	0,440	0,262
100	0,610	0,594	0,537	0,342
150	0,885	0,879	0,811	0,549
250	1,50	1,48	1,41	1,03
400	2,38	2,35	2,28	1,76
662	3,69	3,69	3,63	2,99
1 250	6,09	6,10	6,03	5,25

From: D.T. Bartlett, P. J. Dimbylow and T.M. Francis: "Calculations of the Energy and Angle Dependence of Response of a Simplified Design of Photon Personal Dosimeter and its Relationship with the Recommended ICRU Calibration Quantity" (submitted for publication (1986)), and P. J. Dimbylow and T.M. Francis: "The Calculation of Dose Equivalent Quantities in the ICRU Sphere for Photon Energies from 0,01 to 10 MeV", *Rad. Prot. Dosimetry* 9 (1), pp. 49-53 (1984), for other angles and for spatial and rotational isotropy.

Annex B

Dose equivalent conversion factors for environmental dosemeters

Table B.1 gives conversion data from kerma in air to ambient dose equivalent.

Table B.1 - Conversion of air kerma to ambient dose equivalent for monoenergetic photons of energy E

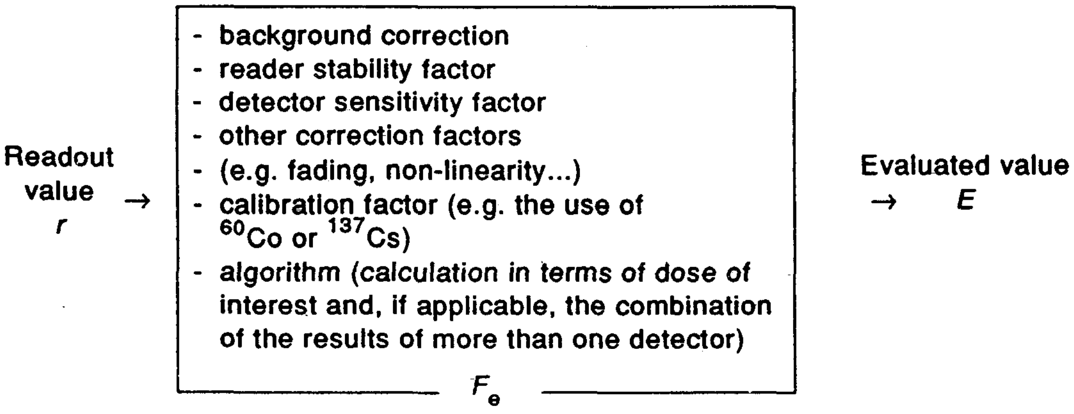
E keV	$H^*(10)/K_a$ Sv/Gy
10	0,01
15	0,32
20	0,60
25	0,86
30	1,10
40	1,47
50	1,67
60	1,74
70	1,75
80	1,72
90	1,68
100	1,65
125	1,56
150	1,49
200	1,40
250	1,35
300	1,31
500	1,23
662	1,20
1 000	1,17
1 250	1,16
3 000	1,13

From: "New Quantities in Radiation Protection and Conversion Coefficients", *Rad. Prot. Dosimetry* 14 (4), pp. 337-343 (1986).

Annex C

Determination of evaluated value E from readout value

To determine the evaluated value from either the ambient dose equivalent or from the individual dose equivalent that a TL dosemeter is expected to measure, at least one and sometimes more TL detectors are read in the TL reader. In order to convert the results of these readout values r into the final answer, a number of steps have to be made, depending on the TLD system being used and how it is used. The following diagram indicates, as an example, what steps may be involved.



Readout value r →

- background correction
- reader stability factor
- detector sensitivity factor
- other correction factors
- (e.g. fading, non-linearity...)
- calibration factor (e.g. the use of ^{60}Co or ^{137}Cs)
- algorithm (calculation in terms of dose of interest and, if applicable, the combination of the results of more than one detector)

F_e

Evaluated value → E

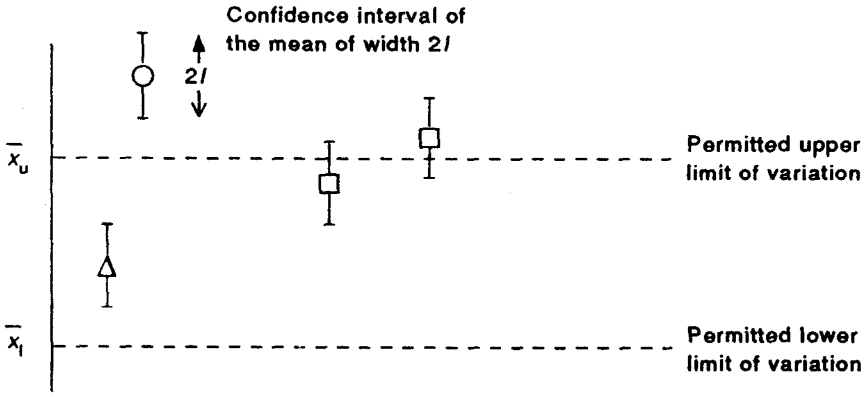
In any particular situation, some of these factors may not be necessary and other factors may have to be introduced. For this reason, in this standard one single factor is assumed to replace the entire process, namely the evaluation factor F_e, which converts the readout value r into the evaluated value E.

Annex D

Confidence limits

D.1 General

If the magnitude of the random uncertainty cf a measured value is a significant fraction of the permitted tolerance of this measured value, the random uncertainty shall be assessed by taking more than one measurement. The number of measurements or the sample size shall be chosen in such a way that the confidence interval obtained for each mean $\bar{x}$ for a confidence level of 95 % lies either within the limits of variation of the measured value permitted in the test (test passed, point Δ in figure D.1) or outside these limits (test failed, point O in figure D.1). If one of the permitted limits of variation x_u or x_l, lies within the confidence interval of the mean (point □ in figure D.1), the number of measurements or the sample size can be increased to reduce the width $2l$ of the confidence interval of the mean $\bar{x}$ in order to reach one of the two cases mentioned above, which are necessary for an unequivocal decision of passing the test or not.


Confidence interval of the mean of width 2l
2l
$\bar{x}_u$
$\bar{x}_l$
Permitted upper limit of variation
Permitted lower limit of variation

IEC 196/91

Figure D.1 - The test is passed if the confidence interval of width $2l$ around $\bar{x}$ lies between the permitted upper and lower limits of variation, $\bar{x}_u$ and $\bar{x}_l$.

In each test it is recommended to start with 10 measurements for each dosemeter. If it turns out to be necessary to reduce the width $2l$ of the confidence interval of the experimental standard deviation, the number of measurements should be increased (see D.2).

Occasionally it is more convenient to carry out a test (including e.g. an irradiation) with a certain number of different dosemeters drawn at random from the batch instead of repeating a number of measurements with the same dosemeter. There are no objections to such a procedure but the random uncertainties of the test results may be increased.

D.2 *Confidence interval for the experimental standard deviation (s)*

The confidence interval for the experimental standard deviation of the means s, is:

$$(s - l_s,\ s + l_s)$$

where l_s is the half-width of the confidence interval of s. If s is calculated from n_s measurements, the upper limit of l_s at a confidence level of 95 % is given by:

$$l_s\,(n_s) = t_{ns} = \sqrt{\frac{0{,}5}{n_s - 1}} \cdot s \qquad (1)$$

By way of example l_s (10) = 0,53 · s is obtained for 10 dosemeters.

D.3 *Mean, $\overline{x}$*

The confidence interval for the mean $(\overline{x})$ is:

$$(\overline{x} - l_i,\ \overline{x} + l_i)$$

where l_i is the half-width of the confidence interval of $\overline{x}$ relative to the i-th set of measurements. When calculating $\overline{x}$ from n_i measurements, the half-width of the confidence interval is given by:

$$l_i = \frac{t_{ni} \cdot s_i}{\sqrt{n_i}} \qquad (2)$$

where s_i is the standard deviation for the i-th group of measurements, and t_{ni} is taken from table D.1 for n_i measurements. For example, for $n_i = 10$, $l_i = 2{,}26 / \sqrt{10} \cdot s_i = 0{,}71 \cdot s_i$.

Table D.1

n_i	t_{ni}
2	12,71
3	4,30
4	3,18
5	2,78
6	2,57
7	2,45
8	2,37
9	2,31
10	2,26
15	2,15
20	2,09
25	2,06
30	2,05
40	2,02
60	2,00
120	1,98
∞	1,96

D.4 *Confidence interval for a combined quantity*

If the limits of variation are stated for a quantity ($\overline{x}$) calculated from k independent means $\overline{x}_1, \overline{x}_2, \overline{x}_3, \dots, \overline{x}_k$:

$$\overline{x} = f(\overline{x}_1, \overline{x}_2, \overline{x}_3, \dots, \overline{x}_k)$$

and the half-width of the confidence interval of the i-th mean is l_i, the half-width (l) of the confidence interval for $\overline{x}$ is given by

$$l = \sqrt{\sum_{i=1}^{k} \left[\frac{\partial f(\overline{x}_1, \overline{x}_2, \overline{x}_3, \dots, \overline{x}_k)}{\partial \overline{x}_i} \right]^2 \cdot l_i^2}$$

Examples:

1) $$\overline{x} = \overline{x}_1 \pm \overline{x}_2 \qquad \text{hence } l = \sqrt{l_1^2 + l_2^2}$$

in general $$\overline{x} = \sum_{i=1}^{n} \overline{x}_i \qquad \text{hence } l = \sqrt{\sum_{i=1}^{n} l_i^2}$$

2) $$\overline{x} = \frac{\overline{x}_1}{\overline{x}_2} \qquad \text{hence } l = \frac{\overline{x}_1}{\overline{x}_2} \sqrt{\left(\frac{l_1}{\overline{x}_1}\right)^2 + \left(\frac{l_2}{\overline{x}_2}\right)^2}$$

3) $$\overline{x} = \frac{\overline{x}_1 - \overline{x}_2}{\overline{x}_1 + \overline{x}_2} \qquad \text{hence } l = \frac{2}{(\overline{x}_1 + \overline{x}_2)^2} \sqrt{(\overline{x}_2 \cdot l_1)^2 + (\overline{x}_1 \cdot l_2)^2}$$

Annex E

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